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Advanced Fuel Cycle Facility
Conceptual Design and NEPA Support Activities

Estimation of AFCF HLW, LLW & TRU-Contaminated Waste Volumes to Support the GNEP PEIS

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NOTICE

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Estimation of AFCF HLW, LLW, and TRU Waste Volumes to Support the GNEP PEIS*

1.0 Introduction

Among its missions, the Advanced Fuel Cycle Facility (AFCF) is designed to develop and demonstrate advanced reprocessing technologies for spent nuclear fuel (SNF), remote fuel fabrication processes for recycling the recovered actinides, and advanced waste processing technologies and waste forms for the radioactive wastes. This white paper describes the approach used and assumptions made to update projected solid† waste volumes for HLW, LLW, and waste contaminated with transuranic nuclides expected to exceed the threshold for Class C low-level waste (LLW)‡. This latter category, commonly referred to as "Greater-Than-Class-C" (GTCC) LLW, is termed "transuranic waste", TRU-contaminated waste or simply TRU waste in this paper. These projections were prepared to support the development of the Programmatic Environmental Impact Statement (PEIS) for the DOE Global Nuclear Energy Partnership (GNEP) initiative, and the DOE Environmental Management (EM) Environmental Impact Statement (EIS) for a GTCC LLW repository.

The AFCF is being designed to support development and engineering-scale demonstration of technologies needed to advance the state-of-the-art for spent nuclear fuel (SNF) reprocessing in support of an expanded use of nuclear energy for electric power generation. Technologies currently under development in the DOE's Advanced Fuel Cycle Initiative (AFCI) program include advanced SNF separations technologies, fabrication of recycle nuclear fuels, qualification of recycle fuel fabrication processes, development of advanced waste processing technologies and advanced waste forms, and development of advanced instrumentation and nuclear materials safeguards technologies.

Reprocessing of SNF results in the generation of HLW, LLW, and TRU-contaminated radioactive solid wastes. Estimates of the volumes of wastes generated are needed to support the design of any waste storage facilities for the AFCF and to evaluate the environmental impacts of waste storage and waste transportation from AFCF to a licensed disposal facility. In addition, estimates of TRU waste volumes generated at AFCF are needed to support the development of the DOE Environmental Impact Statement for disposal of GTCC wastes.

* This white paper was prepared jointly by Charles O. Grigsby, Washington Division of URS, Nick Soelberg, and Eric Yde, both of Idaho National Laboratory.

† Solid waste volumes include the volumes of absorbed gases that are stabilized as solids as well as the solid wastes that result from processing of radioactive liquid wastes.

‡ See 10CFR61.55(a)(2)(iv) and (a)(3)(iv) for the upper threshold of Class C LLW

2.0 Estimates of Radioactive Waste Generation

2.1 AFCF NEPA Data Study Estimates

The AFCF NEPA Data Study,[1] prepared in early 2007 to support the GNEP PEIS, focused on the generation of wastes directly generated by reprocessing SNF, but did not provide estimated generation rates for (a) secondary wastes such as contaminated waste water, solvents, ion exchange (IX) resins, etc., (b) maintenance wastes (primarily spent equipment, filters, light bulbs, fuel storage pool wastes, etc.) and (c) job control wastes (gloves, booties, coveralls, tenting, and other materials used to control the spread of radioactive contamination). The AFCF NEPA Data Study assumed that aqueous wastes and organic-based wastes such as solvents and most job control wastes and some maintenance wastes (spent ion exchange resins from the fuel storage pool water treatment system) would be processed via fluidized bed steam reforming processes to essentially eliminate these wastes and to recover radioactive materials. These secondary and incidental waste streams were not included in the material balances at that time, and so waste characterization and generation rates were not estimated for these waste streams.

AFCF conceptual design has continued since the AFCF NEPA Data Study was performed. This white paper updates some of the waste generation data and provides estimated generation rates for wastes that were not included in the original AFCF NEPA Data Study. The estimates provided in the AFCF NEPA Data Study were based on a bounding analysis for processing very high burnup SNF. The source term used in that study for light water reactor (LWR) SNF was 100 GWd/MTIHM with a 5-year post-irradiation cooling period[*]. The source term used for SNF from the Advanced Recycling Reactor (ARR) (a fast neutron spectrum reactor whose purpose is to produce energy from the fission of transuranium elements recovered from LWR SNF) was 250 GWd/MTIHM with a 1-year cooling period. These source terms were selected for use in the AFCF NEPA Data Study as "bounding" the activity of the SNF to be processed in AFCF. More typical burnups for LWR fuel that is currently in storage range from 40 to 60 GWd/MTIHM, and cooling periods range from 0 to 60 years. Burnups and cooling periods for ARR SNF are expected to be on the order of 90 to 100 GWd/MTIHM and 1-year, respectively, based on current ARR modeling calculations.

Process flowsheets defined for the various AFCF processing operations were used in performing material balances to provide estimates of product and waste masses. Waste volumes were estimated from the calculated waste masses using anticipated waste loadings in the final waste form and using estimates of densities for those waste forms[†]. Finally, the packaged volumes

[*] The burnup of nuclear fuel indicates how much of the original nuclear fuel is converted to fission products. This is measured in terms of the power produced (in gigawatt-days) per metric ton of nuclear fuel. The units used here are GWd/MT or GWd/MTIHM (gigawatt-days per metric ton of initial heavy metal). Thus, high burnup fuel contains more fission products and will generate more fission product waste than low burnup fuel. The post-irradiation cooling period allows short half-life isotopes (that provide very high levels of radiation) to decay, thus reducing the dose for handling and shipping the SNF.

[†] The material balance calculations are on a mass basis. However, the number of waste shipments requires estimates of the packaged waste volumes. To convert from the mass basis to a volume basis requires assumptions about hard-to-estimate material properties (densities, solubilities, loadings, etc.). Waste volume estimates are much less reliable than the waste masses because they necessarily incorporate these material property assumptions.

were estimated by considering the volume and the mass that could fit within the appropriate waste container. The amount of waste in a waste container was determined by either the volume of the waste container (with allowance for packing density) or by the allowable mass of the container.

2.2 *Other Estimates of Waste Generation*

Radioactive waste generation from other GNEP SNF reprocessing facilities has also been estimated in several other studies, but using different levels of rigor and different assumptions for the spent fuel source term, waste treatment options, waste forms, waste loadings, and packaging. The resulting waste masses and volumes differ somewhat because of these different assumptions.

The draft AFCF unit operation description document[2], prepared in support of the ongoing AFCF conceptual design activity, used somewhat different assumptions for LWR fuel burnup and cooling (40 GWd/MT, 10-year cooled) that are more typical of the LWR fuel that might be processed in AFCF. This study provides a more realistic estimate for generation rates of wastes from aqueous separations of LWR SNF, and treated aqueous and organic secondary wastes. Like the AFCF NEPA Data Study, the draft AFCF unit operation description document did not estimate waste generation from maintenance or operations activities (either spent equipment or job control wastes). Neither did this study evaluate waste generation from processing of ARR SNF.

An independent estimate of radioactive waste generation from SNF reprocessing is provided in the September 2007 GNEP Integrated Waste Management Strategy (IWMS) baseline study report[3]. This study, prepared as an overview of waste processing technologies and waste forms from SNF reprocessing, assumed spent LWR fuel with a burnup of 51 GWd/MTIHM, and 20 year cooling. Two reference fuel assemblies were used to estimate the amounts and types of cladding and non-fuel-bearing components (NFBC). Like the AFCF waste generation estimates, this study also estimated wastes generated directly from processing the SNF and did not estimate waste generation from maintenance or operations activities (either spent equipment or job control wastes).

Finally, radioactive waste volumes were estimated for the Consolidated Fuel Treatment Center (CFTC)[4,5] that is planned for commercial-scale reprocessing of SNF. The CFTC estimates were based on reprocessing LWR SNF having a 60 GWd/MT fuel burnup and 5 year cooling. These CFTC studies were prepared to support the GNEP PEIS, and they are the only studies performed in 2007 that provided estimates of radioactive waste volumes generated by facility maintenance and operations.

2.3 *Comparison of AFCF and CFTC Product and Waste Mass Estimates*

The source terms (on the basis of kg/MTIHM for the SNF elements) used for the AFCF and the CFTC mass balance calculations are compared in Table 1. Differences in source terms mean the compositions of the spent fuel, separations products and waste streams for each facility would be different. The amount of burnup achievable in nuclear fuel depends on the initial enrichment and composition of the fuel, and the AFCF source term requires substantially higher enrichments to achieve the high degree of burnup. Typical enrichments for normal LWR fuel show enrichments on the order of 3-5%. However, to achieve the high burnup defined for the source term for AFCF, the initial enrichment had to be increased to about 12%. This change in assumed initial enrichment will be reflected in the relative amounts of actinide (U, Np, Pu, Am, & Cm) elements present in the SNF. Furthermore, the higher burnups will result in higher fission product content. In general, the CFTC fission products average about 67% of the AFCF fission products as shown in Table 1.

Table 1. Comparison of the AFCF and CFTC source terms for LWR SNF.

	AFCF 100 GWD/MTIHM, 5 yr cooled (kg/MTIHM) ~12% initial enrichment	CFTC 60 GWD/MTIHM, 5 yr cooled (kg/MTIHM) ~5% initial enrichment	Ratio of CFTC to AFCF by Element
Ag	0.13	0.13	1.01
Am	1.09	0.78	0.72
Ba	5.57	3.18	0.57
Br	0.07	0.04	0.54
C	0.17	0.17	1.00
Cd	0.24	0.32	1.34
Ce	7.32	4.20	0.57
Cm	0.17	0.22	1.26
Cr		9.41	
Cs	8.51	4.38	0.51
Eu	0.41	0.31	0.75
Gd	0.51	0.37	0.73
He	0.01	0.01	0.63
I	0.52	0.42	0.82
Kr	1.19	0.61	0.51
La	3.77	2.14	0.57
Mo	10.36	6.42	0.62
Nb	0.00	0.72	
Nd	12.72	7.17	0.56
Np	2.03	1.12	0.55
Pd	3.60	3.17	0.88
Pm	0.07	0.03	0.49
Pr	3.44	1.95	0.57
Pu	15.83	14.60	0.92
Rb	1.19	0.58	0.49
Rh	0.95	0.60	0.63
Ru	6.69	4.30	0.64
Sb	0.03	0.04	1.67
Se	0.17	0.10	0.56
Sm	2.31	1.41	0.61

Table 1. Comparison of the AFCF and CFTC source terms for LWR SNF.

	AFCF 100 GWD/MTIHM, 5 yr cooled (kg/MTIHM) ~12% initial enrichment	CFTC 60 GWD/MTIHM, 5 yr cooled (kg/MTIHM) ~5% initial enrichment	Ratio of CFTC to AFCF by Element
Sn	0.13	4.28	32.10
Sr	2.68	1.34	0.50
Tc	2.12	1.25	0.59
Te	1.37	0.91	0.66
U	876.03	922.00	1.05
Xe	15.07	9.52	0.63
Y	1.53	0.75	0.49
Zr	11.75	258.00	21.96

The entries in Table 1 are shown on an elemental basis rather than on the basis of the true compound (typically oxide) in the SNF. Mass balance calculations performed for the separations, fuel fabrication and waste stabilization processes ultimately include the masses of any chemical compounds added to stabilize the final product or waste forms. However, these mass balance calculations do not provide estimates of the bulk densities of these materials that are needed to estimate the volumes of the various product and waste streams.

When scaled to equivalent spent fuel throughputs, the actinide product and HLW mass generation estimates from the AFCF and CFTC projects were in reasonably close agreement as shown in Table 2. These estimates are also in reasonable agreement with the waste estimates from the IWMS[6]. The differences between the estimates shown in Table 2 depend largely on different assumptions made by each project for the burnup of the SNF, for the non-fuel-bearing components (NFBC) such as the assembly hardware that is included in the source term, and for differences in processing efficiencies. These comparisons support the assertion that the product and HLW estimates for the AFCF NEPA Data Study are consistent with other, independently-derived HLW estimates, and suggest that estimates for other waste types, especially for maintenance wastes, job control wastes, and low-level wastes might be reasonably estimated by scaling from the CFTC analysis.

Table 2. Comparison of annual production mass rates for products and wastes from aqueous processing of LWR fuels. AFCF data from reference 1. CFTC data from reference 7.

	AFCF	Scaled AFCF	CFTC
Annual Throughput	75 MTHM	100 MTHM	100 MTHM
LWR Assemblies Processed	150/yr	200/yr	228/yr
Hulls, Inerts	33.1 MT	44.1 MT	41.2 MT
Tc/UDS/metal	1 MT	1.3 MT	2.4 MT
Total Metal Waste	34.1 MT	45.5 MT	43.6 MT
Cs/Sr Waste	14 MT	18.7 MT	9.4 MT
Lanthanide/Fission Product Waste	22 MT	29.3 MT	38.6 MT
UO_3 product	79 MT	105.3 MT	106.8 MT
U/TRU oxide product	1.7 MT	2.3 MT	5.4 MT
U + U/TRU oxide product	80.7 MT	107.6 MT	112.2 MT

2.4 Converting from Mass to Volume

The values presented in Table 2 are the masses of products and wastes from aqueous processing of LWR SNF. Product and waste estimates show better agreement when compared on a mass basis than when compared on a volume basis because there are fewer assumptions involved in calculating masses. However, it is the volumes, particularly the packaged volumes, of the wastes that are of importance in evaluating the storage requirements and transportation impacts from AFCF operations.

Estimating waste volumes requires assumptions about the waste loading in the final waste form, bulk or compacted densities of the final waste forms, and head space left in the waste package when it is full. There are multiple options available for packaging of the different types of wastes. These packaging assumptions also have a bearing on the storage and transportation of the wastes. For example, a Standard Waste Box (SWB)[*] has an internal capacity of 1.88 m^3, and two SWBs can be shipped in a TRUPACT II[†]. On the other hand, up to fourteen 55-gallon drums[‡] (having an internal volume of 0.208 m^3 each) can be shipped in a TRUPACT II. Two SWBs contain 3.76 m^3, but fourteen 55-gal drums contain 2.9 m^3 – 77% of the volume of the two SWBs.

Another consideration in packaging involves determination of the limiting factor in the packaging. Very heavy materials may exceed the weight limit for the package before the package is full. On the other hand, very low density materials may fill the package with a fraction of the allowable weight. To determine the number of packages required for each waste stream, a spreadsheet was developed to perform the calculations of the number of packages that would be required for a given waste volume and mass. Two calculations were performed for each waste stream – the first involved calculating the number of packages required to accommodate the waste volume, and the second involved calculating the number of packages required to hold the waste mass without exceeding the maximum package weight. The number of required packages for that waste form was determined by the larger of these two numbers.

2.5 Waste Types and Dispositions

The AFCF NEPA Data Study[1] identified the waste types expected from processing of LWR and ARR SNF, and from the fuel fabrication activities of the AFCF. In that analysis, some operations wastes (for example, spent ion exchange resins from the fuel storage pool water treatment system, spent filters, and most job control wastes) would be treated under a RCRA Part B permit to recover actinides and to reduce the overall waste volume. On the other hand, the CFTC design assumed that some of the maintenance and most job control wastes could be

[*] A Standard Waste Box is a DOT 7A Type A shipping container that is primarily used as an inner container for transporting transuranic wastes in a TRUPACT II.

[†] A TRUPACT II is a DOT Type B shipping container used for transporting transuranic waste.

[‡] For the sake of consistency, a 55-gallon drum that meets certain testing requirements (49 CFR 173.465) is a DOT 7A Type A (specification) shipping container that can be used for shipping low level wastes or can be used as an inner container in a TRUPACT II. Furthermore, up to 4 ea. 55-gallon drums can fit within a SWB.

compacted, but it did not assume that these waste streams would be thermally treated. Even though the AFCF conceptual design assumes that these waste streams would be thermally treated (which would result in smaller final waste volumes compared to compaction), estimates of the AFCF maintenance and job control waste volumes have been directly scaled from CFTC estimates for the purpose of providing data for the PEIS.

Figure 2 shows the waste streams, proposed treatment or stabilization, and expected disposal pathways for the AFCF wastes that form the basis for the PEIS analysis. This figure revises previous inputs from the AFCF NEPA Data Study (Figure 7) based on the DOE direction to not include volume reduction treatments in the bounding analysis. Each waste stream shown in Figure 2 is identified as HLW, LLW, or TRU waste, and this figure defines the packaging assumptions presented in the section 4 of this white paper.

2.6 AFCF Throughput Scenarios

The final issue to be addressed before estimating AFCF waste generation rates involves the assumptions about throughput of the facility. The initial throughput assumptions for the design basis were directed by the earliest revision of the AFCF F&OR,[8] and those assumptions are shown in Table 1 of the AFCF NEPA Data Study[1]. The AFCF design basis effectively sets the size of the processing equipment and of the overall facility by defining the required throughput and the required storage capacity. The AFCF Design Basis, based on the original F&OR is:

<u>AFCF Design Basis</u>

- Available for operations at least 67% of the year (240 days)
- Aqueous separations capability for processing either:
  - 25 MTIHM of 100 GWd/MTIHM, 5-year cooled[*] LWR fuel, or
  - 1 MTIHM of 250 GWd/MTIHM[†], 1-year cooled ARR fuel
- Electrochemical separations capability for processing:
  - 1 MTIHM of 250 GWd/MTIHM, 1-year cooled[Error! Bookmark not defined.] ARR fuel
- Fuel fabrication capability for fabricating up to:
  - 10 ARR LTAs[Error! Bookmark not defined.]
- SNF storage capacity for up to 1 year's throughput of LWR and ARR SNF
- Product storage capacity for up to 10 years' throughput
- Waste storage capacity as follows:
  - Hazardous wastes – up to 6 months' storage
  - LLW – up to 1 year's throughput
  - HLW – up to 10 years' throughput
  - GTCC (≤100 nCi/g TRU) - up to 10 years' throughput
  - GTCC (>100 nCi/g TRU) - up to 25 years' throughput
  - Cs/Sr – up to 25 years' throughput

[*] Redefined in May of 2007 by AFCF Project Management and incorporated into revision 1 of the AFCF F&OR

[†] Later revised by analogy (e.g., the ARR burnup) with the AFCF Project Management direction in May 2007

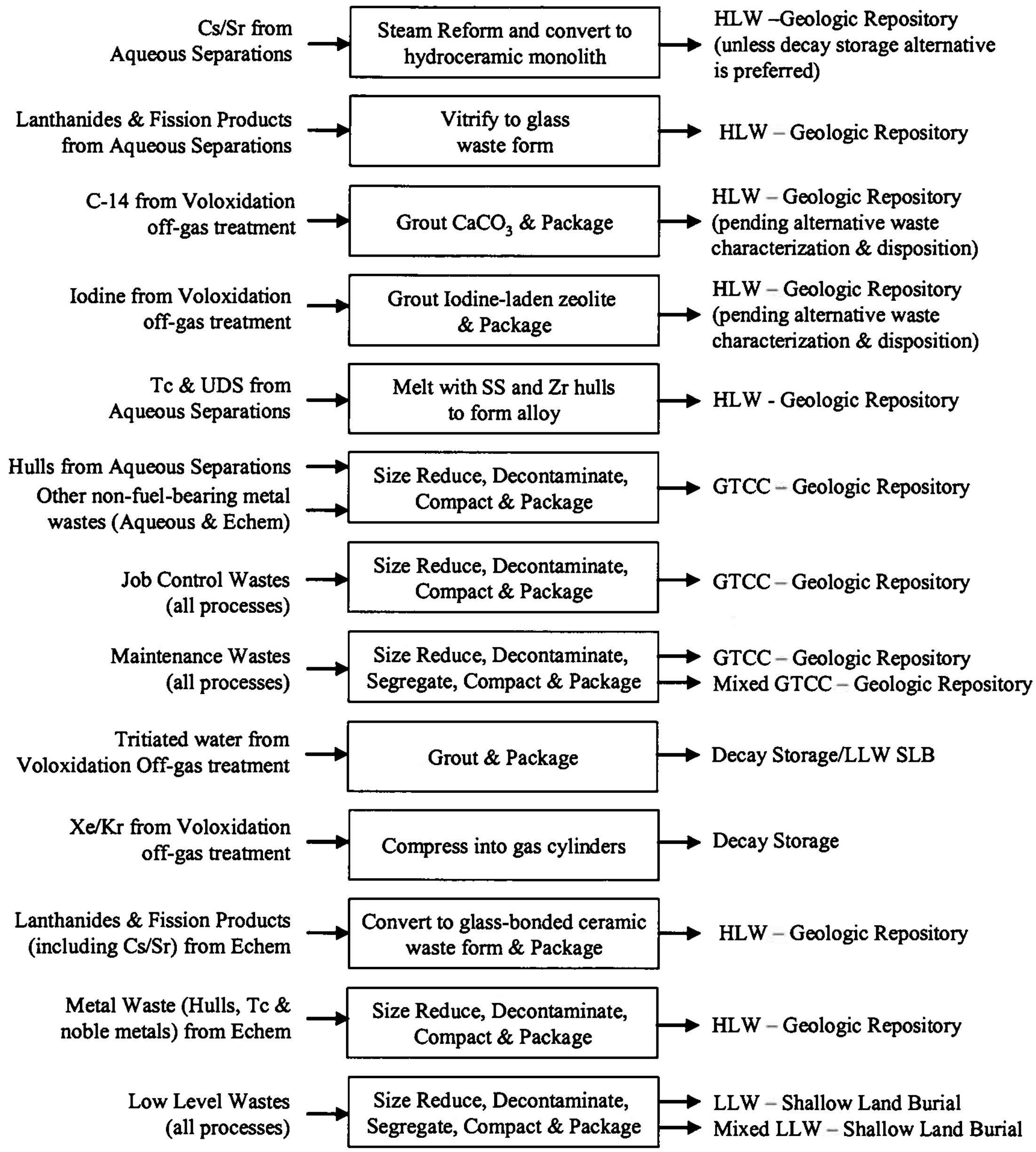

Figure 2. Waste Streams, Treatment Processes, and Disposal Pathways for AFCF Radioactive Wastes.

Because of uncertainty about the actual processing rates, and to provide for some flexibility in the analysis of expected impacts, a "bounding" throughput scenario was prepared to support the NEPA process. The intent of this "NEPA bounding" scenario was to provide an estimate of the maximum expected throughput for a facility that was to be sized according to the AFCF Design Basis but operated at maximum capacity. The AFCF NEPA Bounding Basis is:

AFCF NEPA Bounding Basis

- Available for operations 100% of the year (365 days)
- Aqueous separations capability for processing either:
    - 75 MTIHM of 100 GWd/MTIHM, 5-year cooled LWR fuel, or
    - 2 MTIHM of 250 GWd/MTIHM, 1-year cooled ARR fuel
- Electrochemical separations capability for processing:
    - 2 MTIHM of 250 GWd/MTIHM, 1-year cooled ARR fuel
- Fuel fabrication capability for fabricating up to:
    - 50 ARR LTAs (based on the amount of separated actinide material available)
- SNF storage capacity for up to 1 year's throughput of LWR and ARR SNF
- Product storage capacity for up to 10 years' throughput
- Waste storage capacity as follows:
    - Hazardous wastes – up to 6 months' storage
    - LLW – up to 1 year's throughput
    - HLW – up to 10 years' throughput
    - GTCC (≤100 nCi/g TRU) - up to 10 years' throughput
    - GTCC (>100 nCi/g TRU) - up to 10 years' throughput
    - Cs/Sr – up to 10 years' throughput

The NEPA Bounding Basis is the throughput basis for the analysis presented in the AFCF NEPA Data Study.

In May of 2007, the AFCF Project Management office provided direction for advancement of the conceptual design of the AFCF. This direction addressed throughput rates for the AFCF Design Basis and did not affect the throughput assumptions for the AFCF NEPA Bounding Basis. The direction was to design and size the AFCF facility and equipment to be capable of producing up to 8 LTAs/year within the 240 day operating period (the AFCF "Design Basis"), but to expect that only 4 LTAs would be required each year for the qualification of the fuel fabrication process (the AFCF "Operating Basis"). Furthermore, the throughput of aqueous separations was to be based on an LWR SNF source term that would be more typical of the LWR fuel expected to be in the spent fuel inventory at the time AFCF operations were projected to begin. That source term was selected to be 40 GWd/MTIHM, 20-year cooled LWR SNF. This AFCF Project Management direction was formalized in Revision 1 of the AFCF F&ORs. It also redefines the AFCF Design Basis and effectively defines an "AFCF Operating Basis".

This Nominal Operating Basis is given below:

AFCF Nominal Operating Basis

- Available for operations at least 67% of the year (240 days)
- Aqueous separations capability for processing:
    - 12.5 MTIHM of typical (40 GWd/MTIHM, 20-year cooled) LWR fuel
- Electrochemical separations capability for processing:
    - No specific capability is defined but 1 MTIHM of ~90-100? GWd/MTIHM, 1-year cooled ARR fuel is assumed*
- Fuel fabrication capability for fabricating up to:
    - 4 ARR LTAs
- SNF, Product and Waste Storage bases are not defined, but are assumed to be based on 10 years' throughput for either the AFCF Design Basis or the AFCF Nominal Operating Basis

* Later revised by analogy (e.g., the ARR burnup) with the AFCF Project Management direction in May 2007

The AFCF Design Basis and the AFCF Nominal Operating Basis are defined for the purpose of specifying throughput for the AFCF to support the design of this facility. The AFCF NEPA Bounding Basis was defined for the purpose of providing a bounding estimate of the impacts from construction and operation of the AFCF to support the NEPA process.

In principle, the AFCF conceptual design that forms the basis of the NEPA bounding estimates could house equipment that, operated at its maximum capacity and with maximum facility availability, could achieve the NEPA bounding throughput for the separations processes. There are many reasons why this level of production could rarely be achieved and could never be sustained, thus the designation as "bounding". However, this "bounding" basis can be considered to be the "Maximum Operating Basis" for the AFCF.

Estimates of the annual radioactive waste generation from AFCF were multiplied by the expected 50 year lifetime of the facility to provide an estimate of the lifetime waste generation from AFCF operations. These resulting lifetime waste volumes are excessively conservative. Realistic operation of the AFCF would involve different throughputs at different times during the lifetime of the facility, depending on the need for test assemblies. Following the throughputs for the design and nominal/operating *bases* described above, three operating *scenarios* – Maximum, Design, and Nominal – were defined as shown in Table 3. The Design and Nominal Operating Scenarios are based on the same mass throughputs as the Design and Nominal Operating Bases, but the source terms correspond to the source term of the Maximum Operating Scenario*.

Table 3. AFCF Operating Scenarios for the GNEP PEIS Analysis

Specification	Maximum Operating Scenario	Design Operating Scenario	Nominal Operating Scenario
LWR SNF	75 MTHM/yr	25 MTHM/yr	12.5 MTHM/yr
Fast reactor SNF	2 MTHM/yr	1 MTHM/yr	1 MTHM/yr
LWR SNF burnup	100 GWD/MTHM	100 GWD/MTHM	100 GWD/MTHM
Fast reactor SNF burnup	250 GWD/MTHM	250 GWD/MTHM	250 GWD/MTHM
LWR SNF cooling period	> 5 years	> 5 years	> 5 years
Fast reactor SNF cooling period	> 1 year	> 1 year	> 1 year
Fuel fabrication rate	50 LTAs/yr	8 LTAs/yr	4 LTAs/yr

Given the likelihood that the AFCF would operate at high throughput for some portion of its lifetime and at lower throughput for the remainder of its lifetime, an "expected" lifetime waste generation estimate was developed assuming that the AFCF would operate at the Maximum Operating Scenario throughput for ten years and at the Design Operating Scenario throughput for the remaining 40 years of the AFCF design lifetime.

* The distinction between the "design basis" and the "design operating scenario" is subtle, but important. The "design basis" is supported by material balance calculations performed using the specific source term identified in the definition of the design basis on page 14. On the other hand, there are no material balance calculations for the "design operating scenario", and any estimates for this scenario are based on assumed linear scaling from the "maximum operating scenario". This linear scaling for the design operating scenario is therefore based on the 100 GWd/MTIHM, 5-yr cooled source term rather than the 40 GWd/MTIHM, 20 year cooled source term defined for the design basis.

3.0 Considerations for Scaling Waste Generation Estimates

Some of the AFCF waste generation estimates provided in this white paper have been scaled from the CFTC waste generation studies described earlier[4]. Scaling waste generation estimates requires understanding of considerations that can be broadly lumped into two types of scaling factors: external and internal factors. External scaling factors would be those factors that account for differences in waste generation between facilities of different inherent sizes, for example, extrapolating waste generation volumes for TRU-contaminated waste and for LLW from the 800 MT/yr CFTC facility to the 75 MT/yr maximum operating throughput for the AFCF. Internal scaling factors account for differences in operating tempo within a facility of fixed size – for example, from the 75 MT/yr maximum operating throughput for AFCF to the design or the nominal operating throughputs for the same facility.

Some waste generation scales linearly with the throughput. For example, the activated metal waste and the fission products from irradiated SNF should not depend on the facility scale but should depend only on properties of the SNF assemblies that are processed, the processing rate, and the assumed waste forms. On the other hand, some wastes may appear to scale inversely with throughput – an example would be the case where significant replacement of contaminated equipment would result in high maintenance and job control waste volumes and low throughput because the available processing time is limited. In that case, the throughput is not an independent variable but depends on operational considerations. Some waste will be generated by the mere fact that the facility is in operation – for example, spent ion exchange resins from the spent fuel storage pool water treatment system, and wastes from normal janitorial activities for the facility. This section defines three parameters – throughput, number of workers, and size of facility - used for estimating waste generation rates for different types of radioactive wastes.

For the most part, the scale of the processing equipment is set by the size of the spent fuel received for processing and the size of the LTAs fabricated. The impact of changing facility input and/or output has little impact on the baseline number of employees required to operate, maintain, and safeguard the facility.

The AFCF will require a staff of facility operations, safety, radiation protection, engineering, maintenance, security and other personnel to operate and maintain the facility and equipment. Most of the AFCF employees required for the facility operation even when there are no processing activities, and most employees will not be involved in processing operations. The number of employees required to operate the AFCF is largely independent of the throughput of the facility in the range of planned processing throughputs (aqueous processing of 12.5 to 75 MT/yr LWR SNF, aqueous or electrochemical processing of 1 to 2 MT ARR SNF, fabrication of 4 to 50 ARR LTAs/year).

3.1 Waste Generation that Scales with Processing Throughput

The wastes derived from processing SNF will scale with the number of fuel assemblies processed per year; the mass of non-fuel bearing components per assembly; the initial fuel mass, and the burnup and cooling period for the fuel. The variations in number of assemblies processed – in other words, the annual mass processed – is far more important in determining the annual HLW waste generation than the relatively minor variations in masses of NFBC per assembly or the variations in burnup and cooling period. Thus, the waste masses and volumes are assumed to scale with facility throughput for HLW and for those TRU wastes that are directly derived from SNF.

3.2 Waste Generation that Scales with Number of Radiation Workers

Job control wastes such as contaminated personal protective clothing, tenting materials used to control the spread of contamination, cleaning materials used in decontamination activities, etc. will scale with the number of operations where job control materials are required – the number of personnel making entry into contaminated areas, the number of decontamination operations and the amount of cleaning material used per operation. An approximate measure of the job control waste generation is given by the total annual volume of job control wastes divided by the total number of radiation workers. Thus, to first order, job control wastes are assumed to scale with the number of radiation workers and the number of entries into radiological areas made by each worker.

This "external factors" estimate applies to the maximum operating throughput for the facility. The design operating throughput and the nominal operating throughput involve essentially the same size facility and the same number of radiation workers as for the maximum throughput AFCF case, with the difference in throughput being the result of internal factors such as a reduced operating tempo. Thus, a second order effect is needed to account for the operating tempo of the AFCF. At a high throughput, there will be less downtime and fewer operating cycles. This high throughput case should result in relatively lower volumes of job control wastes and maintenance wastes because there would be fewer entries into radiological areas while the facility is operating at a high tempo. Lower throughput could involve more decontamination for equipment repair and changeout and therefore, relatively higher generation of job control wastes. For the purposes of this analysis, it is assumed that the annual average waste generation rates of these kinds of waste streams would decrease, but not as much as would be proportional to the decreased SNF throughput for the lower operating tempos. This assumption accounts for the expected increase in job control waste generation from cleanup and equipment replacement activity.

3.3 Waste Generation that Scales with Facility Footprint

Maintenance wastes are primarily generated by equipment repair and replacement, and include the spent process equipment, manipulators, light bulbs, filters, etc. from within the hot cell. Maintenance wastes will tend to scale with the size of the facility (the number of manipulators, the number of skids of process equipment, redundancy of process equipment) and with the operating tempo (increased wear and tear following periods of high operating tempo, less wear and tear results from lower operating tempo).

4.0 AFCF Waste Generation Estimates

Because the AFCF studies to date have not rigorously estimated AFCF maintenance, job control, and low-level waste generation rates, these waste generation rates were estimated by scaling from the CFTC analysis performed in reference 4.

4.1 Estimation of Waste Volumes for Each AFCF Module

This section develops waste generation estimates for each of the AFCF waste streams from each of the four main AFCF modules (aqueous separations, electrochemical separations, fuel fabrication, and the Process Support and Development (PSD) Module) based on the CFTC waste volume estimates presented in reference 4.

The results of these estimates for the Centralized Greenfield case are shown in Table 4. The top portion of this table compares annual waste volume estimates from the AFCF NEPA Data Study with annual waste volume estimates scaled from the CFTC (reference 4). The bottom portion of this table shows the bounding AFCF lifetime estimates based on maximum throughput for 50 years as well as "expected" lifetime waste volume estimates based on the assumption that aqueous separations and fuel fabrication throughputs are at the maximum throughput for ten years and at the design throughput for the remaining forty years of AFCF lifetime. This "expected lifetime" waste volume estimate was used as the basis for reporting expected TRU-contaminated waste volumes for the EM GTCC EIS data call. Table 5 shows the same type of information as is shown in Table 4, with the difference that Table 5 applies to the Distributed AFCF alternatives. The information in Table 5 is calculated following the assumption (from reference [9]) that the Distributed modules require 10% increase in throughput over the equivalent Centralized Greenfield case.

4.1.1 Aqueous Separations Waste Volume Estimates

The wastes described in this section include the high-level and TRU-contaminated wastes derived from disassembly and chopping of LWR SNF, solidified and stabilized fission product wastes, spent equipment and tooling used in processing the spent fuel, and job control wastes from operations and maintenance activities. These wastes are from the aqueous separations processes.

The packaged volumes for the aqueous separations waste forms for HLW (consisting of the Cs/Sr, Tc, and La/FP streams), and for spent hulls and other non-fuel bearing components (NFBC) (called "Hulls" on the table), which are assumed to be TRU waste due to TRU contamination and activation products in the metal, are based on estimates in the AFCF NEPA data study. Note that the "Tc" waste stream also contains undissolved solids (UDS), and that the majority of the mass of this waste stream is stainless steel from contaminated NFBC and spent hulls, required to result in a primarily Fe/Zr alloy that also contains alloyed reduced Tc metal and UDS.

Table 4. Packaged Waste Volume Estimates and 50-year Lifetime Volume Estimates for HLW and TRU Wastes for the AFCF Centralized Greenfield Alternative.

	Centralized Greenfield AFCF												
	Aqueous Separations				Electrochemical Separations			Fuel Fabrication			Process Support & Development	Bounding AFCF Annual Packaged Waste Volume	Number and Type of Packages per year
	NEPA Data Study (75 MT/yr)	Scaled from CFTC based on Throughput			NEPA Data Study (2 MT/yr)	Scaled from CFTC based on Throughput		NEPA Data Study (50 LTAs)	AFCF Program Guidance on Throughput		@ 10% of Bounding Volumes from Aqueous, Echem & Fuel Fab		
		75 MT/yr	25 MT/yr	12.5 MT/yr		2 MT/yr	1 MT/yr		8 LTAs	4 LTAs			
Packaged Waste	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	
Cs/Sr Cermet (HLW) [1]	7.78	7.3	2.4	1.2	0.15	0.2	0.1				0.7	8.0	420 3" x 10' canisters
Vitrified La/FP (HLW) [1]	9.78	12.9	4.3	2.2	1.65	2.6	1.3				1.6	17.3	13 HLW canisters
Grouted Carbon-14 (HLW)	4.50											5.0	30 ea 55-gal drums
Grouted Iodine (HLW)	0.90											1.0	5 ea 55-gal drums
Tc/SS/Zr Alloy (HLW) [2]	1.03	1.0	0.3	0.2	1.49						0.1	1.1	2 HLW canisters
Compacted Hulls (TRU Waste) [3]	3.62	5.9	2.0	1.0	2.88	4.4	2.2				1.03	11.3	15 HLW canisters
Maintenance (TRU Waste)		8.2	2.7	1.4		5.7	2.9	4.6	1.5	0.8	1.8	20.3	11 SWBs or equivalent
Maintenance (mixed-TRU)		7.2	2.4	1.2		5.0	2.5	4.0	1.3	0.7	1.6	17.9	10 SWBs or equivalent
Job Control (TRU Waste)		300	200	150		200	100	100	70	50	60.0	660	350 SWBs or equivalent
Grouted HTO (decay storage/LLW)	0.006											0.13	1 ea 35-gal drum
Compressed Kr/Xe (decay storage)													3500 ea 2-liter cylinders
Low Level Waste		1200	800	600		800	400	400	280	200	240.0	2640	1585 SWBs or equivalent
Mixed LLW		1.5	0.5	0.3		1.0	0.5	0.5	0.4	0.3	0.3	3.4	2 SWBs or equivalent

[1] Cs/Sr HLW from Electrochemical Separations is included in the La/FP wastes

[2] Tc HLW volume estimates scaled from the CFTC are approximately one-half of the Tc HLW volume estimates from the AFCF NEPA Data Study. The CFTC volumes for aqueous processing shown in this table are scaled from the AFCF NEPA Data Study volumes rather than from the calculated CFTC volumes.

[3] The Hulls TRU Waste waste volume for electrochemical separations (4.4 m3/yr) is taken from AFCF NEPA Data Study calculations and is the sum of the Tc/SS/Zr alloy volume (1.49 m3/yr assuming the density of steel) and the volume of the inert fuel pieces (2.88 m3/yr) at 50% of the density of steel. The hulls/inert assembly waste masses depend heavily on assumptions about the assembly hardware included in the source term(s), and the volumes depend on the assumed void fraction.

Bounding and Expected Lifetime HLW and TRU Waste Waste Volumes for Centralized Greenfield AFCF

Expected Lifetime Waste Volumes based on:

aqueous separations - 10 years @ 75 MT/yr + 40 years @ 25 MT/yr
electrochemical separations - 50 years @ 1 MT ARR SNF/yr (operating case per AFCF F&OR)
fuel fabrication - 10 years @ 8 LTAs/yr + 40 years @ 4 LTAs/year
PSD - 50 years @ 10% of Maximum Annual Packaged Waste Volume (75 MT/yr aqueous + 2 MT/yr echem + 50 LTAs/yr fuel fab)

	Aqueous Separations				Electrochemical Separations			Fuel Fabrication			Process Support & Development	Bounding (white) and Expected (blue) AFCF Lifetime Packaged Waste Volume	Bounding (white) and Expected (blue) AFCF Lifetime number of Packages
		75 MT/yr	25 MT/yr	12.5 MT/yr		2 MT/yr	1 MT/yr	~50 LTAs	8 LTAs	4 LTAs			
		m^3	m^3	m^3		m^3	m^3	m^3	m^3	m^3	m^3	m^3	
Bounding 50 Year HLW Waste Volume		1,059	353	177		142	71	0	0	0	120	1,322	21,000 Cs/Sr canisters 750 HLW canisters
Bounding 50 Year TRU Waste Volume		16,065	10,355	7,678		10,757	5,379	5,431	3,644	2,572	3,225	35,479	750 HLW canisters 18,550 SWB equivalents
Expected Lifetime HLW Volume	494				71			0			120	686	10,900 Cs/Sr canisters 384 HLW canisters
Expected Lifetime TRU Waste Volume	11,497				5,379			2,786			3,225	22,887	360 HLW canisters 12,770 SWB equivalents

Table 5. Packaged Waste Volume Estimates and 50-year Lifetime Volume Estimates for HLW and TRU Wastes for the AFCF Distributed Facility Alternatives.

	Distributed AFCF Modules												
	Aqueous Separations				Electrochemical Separations			Fuel Fabrication			Process Support & Development	Bounding AFCF Annual Packaged Waste Volume	Number and Type of Packages per year
	NEPA Data Study (75 MT/yr)	Scaled from CFTC based on Throughput			NEPA Data Study (2 MT/yr)	Scaled from CFTC based on Throughput		NEPA Data Study	AFCF Program Guidance on Throughput		@ 10% of Bounding Volumes from Aqueous, Echem & Fuel Fab		
		75 MT/yr	25 MT/yr	12.5 MT/yr		2 MT/yr	1 MT/yr	(50 LTAs)	8 LTAs	4 LTAs			
Packaged Waste	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	
Cs/Sr Cermet (HLW) [1]	8.6	8.0	2.7	1.3	0.2	0.2	0.1				0.8	8.8	462 3" x 10' canisters
Vitrified La/FP (HLW)[1]	10.8	14.2	4.7	2.4	1.8	2.9	1.5				1.7	19.1	14.3 HLW canisters
Grouted Carbon-14 (HLW)	5.0											5.4	33 ea 55-gal drums
Grouted Iodine (HLW)	1.0											1.1	5.5 ea 55-gal drums
Tc/SS/Zr Alloy (HLW)[2]	1.1	1.1	0.4	0.2	1.6						0.1	1.2	2.2 HLW canisters
Compacted Hulls (TRU Waste)[3]	4.0	6.5	2.2	1.1	3.2	4.8	2.4				1.1	12.4	16.5 HLW canisters
Maintenance (TRU Waste)		9.0	3.0	1.5		6.3	3.2	5.0	1.7	0.8	2.0	22.4	12 SWBs or equivalent
Maintenance (mixed-TRU)		7.9	2.6	1.3		5.6	2.8	4.4	1.5	0.7	1.8	19.7	11 SWBs or equivalent
Job Control (TRU Waste)		330	220	165		220	110	110	77	55	66	726	385 SWBs or equivalent
Grouted HTO (decay storage/LLW)												0.1	1.1 ea 35-gal drum
Compressed Kr/Xe (decay storage)													3850 ea 2-liter cylinders
Low Level Waste		1,320	880	660		880	440	440	308	220	264	2,904	1744 SWBs or equivalent
Mixed LLW		1.7	0.6	0.3		1.2	0.6	0.6	0.4	0.3	0.3	3.7	2.2 SWBs or equivalent

[1] Cs/Sr HLW from Electrochemical Separations is included in the La/FP wastes

[2] Tc HLW volume estimates scaled from the CFTC are approximately one-half of the Tc HLW volume estimates from the AFCF NEPA Data Study. The CFTC volumes for aqueous processing shown in this table are scaled from the AFCF NEPA Data Study volumes rather than from the calculated CFTC volumes.

[3] The Hulls TRU Waste waste volume for electrochemical separations (4.4 m3/yr) is taken from AFCF NEPA Data Study calculations and is the sum of the Tc/SS/Zr alloy volume (1.49 m3/yr assuming the density of steel) and the volume of the inert fuel pieces (2.88 m3/yr) at 50% of the density of steel. The hulls/inert assembly waste masses depend heavily on assumptions about the assembly hardware included in the source term(s), and the volumes depend on the assumed void fraction.

Bounding and Expected Lifetime HLW and TRU Waste Waste Volumes for Distributed AFCF Modules

Expected Lifetime Waste Volumes based on:

aqueous separations - 10 years @ 75 MT/yr + 40 years @ 25 MT/yr
electrochemical separations - 50 years @ 1 MT ARR SNF/yr (operating case per AFCF F&OR)
fuel fabrication - 10 years @ 8 LTAs/yr + 40 years @ 4 LTAs/year
PSD - 50 years @ 10% of Maximum Annual Packaged Waste Volume (75 MT/yr aqueous + 2 MT/yr echem + 50 LTAs/yr fuel fab)

	Aqueous Separations Module				Electrochemical Separations Module			Fuel Fabrication Module			Process Support & Development Module	Bounding (white) and Expected (blue) AFCF Lifetime Packaged Waste Volume	Bounding (white) and Expected (blue) AFCF Lifetime number of Packages
		75 MT/yr	25 MT/yr	12.5 MT/yr		2 MT/yr	1 MT/yr	~50 LTAs	8 LTAs	4 LTAs			
		m^3	m^3	m^3		m^3	m^3	m^3	m^3	m^3	m^3	m^3	
Bounding 50 Year HLW Waste Volume		1,165	388	194		157	78				132	1,454	23,100 Cs/Sr canisters 835 HLW canisters
Bounding 50 Year TRU Waste Volume		17,672	11,391	8,445		11,833	5,917	5,974	4,008	2,829	3,548	39,027	825 HLW canisters 20,400 SWB equivalents
Expected Lifetime HLW Volume		544			78			0			132	754	12,000 Cs/Sr canisters 400 HLW canisters
Expected Lifetime TRU Waste Volume		12,647			5,917			3,065			3,548	25,176	400 HLW canisters 14,050 SWB equivalents

The AFCF volume estimate for the lanthanide/fission product (La/FP) HLW from the AFCF NEPA Data Study is shown in Table 4 as 7.78 m^3/yr. The corresponding value scaled from the CFTC is 7.3 m^3/yr. The difference between these numbers is very small, and could easily be accommodated by a slight (~6%) change in the assumed bulk density of this waste stream. For the annual volume estimates and for the lifetime volume estimates, this analysis retained the 7.3 m^3/yr value as representative of the La/FP HLW volume.

The AFCF estimated volume of the Tc waste stream (1.03 m^3/yr) is about twice the value estimated by scaling the amount of the Tc waste stream estimated for the 800 MT/yr CFTC facility (0.5 m^3/yr). There are a variety of reasons for this difference, including significant differences in the source terms used for LWR in the AFCF and the EAS studies. To ensure that the waste volumes presented in the GNEP PEIS can reasonably be expected to bound the actual operating case, this paper doubled the calculated CFTC scaled volume for this waste stream (maximum operating throughput case) to correspond to the packaged volume presented in the AFCF NEPA Data Study. This change results in the generation of one additional HLW container generated per year.

Maintenance waste generation rates have not yet been rigorously estimated for AFCF. The generation of maintenance wastes is proportional to the facility size, and for a fixed facility size, these waste volumes vary with the spent fuel throughput. For the PEIS, the generation of maintenance waste for the AFCF was estimated by scaling from the 800 MT/yr throughput rate for the CFTC to the three assumed AFCF throughputs (75, 25, and 12.5 MT/yr). For example,

$$V_{maint\ waste@75MT/yr} = V_{maint\ waste@800MT/yr} \ x \ \frac{75}{800} = 88m^3 \ x \ 0.0937 = 8.2m^3$$

This same approach is used to calculate other aqueous processing waste volumes for all three AFCF throughputs described above and shown in Table 4. Maintenance waste generation from aqueous separations was less, but not proportionately less, for the lower AFCF throughput conditions (compared to the maximum throughput condition). Maintenance waste generation for electrochemical separations was assumed to scale with the two different AFCF ARR SNF throughputs.

Job control wastes have also not yet been rigorously estimated for the AFCF. Discussion of how AFCF job control waste estimates were estimated from the CFTC estimates is deferred to section 4.2 of this white paper.

4.1.2 Electrochemical Separations Waste Estimates

The wastes described in this section include the high-level and TRU-contaminated wastes derived from disassembly and chopping of ARR SNF, solidified and stabilized fission product wastes, spent equipment and tooling used in processing the spent fuel, and job control wastes from operations and maintenance activities. These wastes are from the electrochemical separations processes.

The AFCF NEPA Data Study estimates the masses of waste generation from electrochemical separations of ARR SNF (not including maintenance and operations wastes), but it does not assume densities for these waste streams and convert the masses to volumes. The CFTC waste estimates do not include estimates of waste generation from electrochemical separations of ARR SNL.

In contrast with the aqueous separations process, the electrochemical separations process does not necessarily require separate Cs/Sr and lanthanide fission product waste streams. The entry for Cs/Sr cermet waste in Tables 4 & 5 is therefore highlighted in red to show that this waste is included in the vitrified La/FP wastes from electrochemical separations and from aqueous separations (which are also highlighted in red). The total volume of vitrified La/FP (including the Cs/Sr from electrochemical separations) is used as the basis for estimating the PS&D waste volume for this vitrified waste stream.

The electrochemical separations process reduces many of the fission products and the actinides in the electroreduction salt bath, causing them to enter the molten salt phase. However, the hulls and some of the fission products are not electrochemically reduced and are separated from the molten salt bath as metal. These metals are melted in a furnace to produce a metal alloy waste form containing Tc and other fission products. If necessary, zirconium is added to lower the melting point of the alloy. For the purposes of estimating the electrochemical separations waste volumes, the estimated volume of the Tc-Zr-stainless steel alloy and the estimated volume of the compacted hulls and inert fuel pieces from the AFCF NEPA Data Study were used as the starting point for the CFTC scaled volume estimates. The AFCF NEPA Data Study showed annual volume estimates for these electrochemical separations metal waste streams of 1.49 and 2.88 m^3/year, respectively, as shown in Table 4. For the CFTC scaled estimates, these two waste streams were treated as a single metal waste stream with an annual volumetric rate of 4.4 m^3/yr (1.49 + 2.88 = 4.37), and this combined stream is listed in Table 4 (and in Table 5) as TRU waste. A refinement of this analysis would reclassify some of this TRU waste as HLW – increasing the number of HLW canisters containing the Tc-Zr-stainless steel alloy (HLW) by 2 canisters/yr – and decreasing the number of HLW canisters containing compacted hulls and other NFBC by 2-3 HLW canisters/yr.

Maintenance wastes are primarily spent equipment, components, and tooling used in repairing or replacing the equipment. Because the aqueous separations processes and the throughput bases are distinctly different from the electrochemical separations processes, the maintenance wastes for electrochemical separations were assumed to scale with processing area size rather than with throughput. The scaling factors used for maintenance wastes were taken from estimates of construction and materials impacts that are presented in Table 5 of reference 9. These scaling factors are proportional to the size of shielded processing area needed for process equipment, material handling equipment, and other facility support equipment. The electrochemical separations maintenance wastes were derived as follows:

$$V_{echem\,maint\,wastes@2MT/yr} = V_{aqueous\,maint\,wastes@75MT/yr} \; x \; \frac{35\%}{50\%} = 8.2\,m^3/yr \;\; x \;\; 0.7 = 5.7\,m^3/yr$$

where the electrochemical processing construction and material impacts are estimated to be 35% of the AFCF facility baseline construction and materials impacts, and the aqueous processing construction and material impacts are estimated to be 50% of the AFCF baseline facility construction and materials impacts.

Job control waste volume estimates for electrochemical processing are discussed in section 4.2 of this white paper.

4.1.3 Fuel Fabrication Waste Estimates

There are no HLW or Hulls wastes generated in the fuel fabrication operations. However, there will be maintenance wastes and job control wastes from fuel fabrication that are assumed to be TRU wastes. The maintenance wastes from fuel fabrication are estimated following the procedure described in section 4.1.2, above, for estimating maintenance wastes from electrochemical separations processing. The only difference is that reference 9 identifies the fuel fabrication construction and materials impacts as being 28% of the AFCF baseline facility impacts.

4.1.4 Process Support and Development Facility Waste Estimates

The generation rates for AFCF Process Support and Development facility wastes were estimated to be 10% of the combined total of aqueous separations (at 75 MT/yr SNF input rate), electrochemical separations (at 2 MT/yr) and fuel fabrication wastes (at 50 LTAs per year) in accordance with assumptions from reference 9.

4.2 Estimates of Job Control Waste Volumes for Each AFCF Module

Based on Savannah River Site operating experience, job control wastes for an 800 MT/yr commercial aqueous separations plant were estimated to be 790 m^3/yr and involve 1657 radiation workers[4]. This gives an average annual waste generation rate of 0.48 m^3/yr per radiation worker in an aqueous separations facility. Job control waste generation from electrochemical separations, fuel fabrication, and process support and development activities would likely be higher than for aqueous separations because these processes involve unconfined transfer of materials (removing electrodes from salt baths, dusting during transfers of powders) or increased frequency of decontamination for equipment replacement that would likely result in more frequent cleaning operations than for aqueous separations processes. To account for this likely increase, we assumed that the job control waste generation rates for AFCF were, on average, 60% larger per worker than were estimated for the CFTC. Thus, we took the AFCF annual job control waste generation rate for the maximum operating scenario to be 0.76 m^3/yr per worker. For the estimated 855 radiation workers at AFCF, this would result in a calculated annual job control waste volume of 652 m^3/yr which was rounded up to 660 m^3/yr. This total job control waste volume was then assumed to be distributed among the process modules as shown in Table 6.

Table 6. Distribution of Estimated Annual Job Control Waste Volumes among AFCF Processing Modules for the Maximum Operating Throughput	
Aqueous Separations including LWR SNF receipt, cask unloading, cask washdown, wet storage, head-end processing, aqueous separations processing, product solidification and waste solidification	300 m^3
Electrochemical Separations including ARR SNF receipt, dry storage, head-end processing, electrochemical separations, and waste processing	200 m^3
Fuel Fabrication including feed conditioning, fuel formation, pellet sintering, pellet grinding, fuel encapsulation, and LTA assembly	100 m^3
Process Support and Development	60 m^3
Total	**660 m^3**

Other factors can affect the amount of maintenance and job control wastes more significantly than the spent fuel processing rate or the numbers of radiation worker staff. The estimated amounts of TRU-contaminated maintenance and job control waste may be conservatively high, if the CFTC estimates were made based on historical generation rates of similar waste streams at spent fuel processing facilities. These historical data may not account for design and operation to characterize, segregate, decontaminate, and minimize TRU waste streams consistent with current and future expected waste minimization practices. These data also do not account for treatment to reduce the mass and volume of waste streams that are suited to thermal treatment to evaporate water, destroy organic constituents, and consolidate the residual inorganics in a waste form. Thermal treatment is known to reduce the mass and volume of some waste streams by at least 10-100x. Even without considering volume reduction through thermal treatment, these historical data may not account for volume reduction of up to 10x that is often possible through compaction.

The large amounts of estimated maintenance wastes and job control wastes might be reduced by a factor of 10 to100 by assuming thermal treatment or compaction of suitable waste streams treatment to reduce waste mass and/or volume.

5.0 Waste Volume Estimates for Distributed AFCF Modules

The generation rates shown in Table 5 for the Distributed modular AFCF configuration were assumed to be 10% larger than those estimated for the centralized Greenfield AFCF in accordance with assumptions from reference 9. The 10% increase is assumed to account for losses of efficiency, extra activities, and redundant activities, that result in somewhat higher waste generation for the Distributed facility case compared to the Greenfield facility case.

6.0 Lifetime Waste Volume and Storage Area Estimates

The annual HLW and TRU waste volume estimates for each of the aqueous separations throughput cases, for the electrochemical separations, for the three fuel fabrication cases and for the Process Support and Development Facility were used to project bounding 50-year lifetime AFCF HLW and TRU waste volume estimates. These results are presented in the lower sections of Tables 4 and 5 for the Centralized Greenfield and the Distributed AFCF modules, respectively.

The waste volume estimates based on assuming 50-year operation at the NEPA bounding throughput basis far exceed the likely HLW and TRU waste volumes over the 50-year design lifetime of the AFCF. More likely "expected" lifetime HLW and TRU waste volumes from aqueous separations were derived using the following rationale for providing more realistic estimates of the lifetime waste volumes:

- Aqueous separations: 10 years at 75 MT/yr + 40 years at 25 MT/yr
- Electrochemical separations: 50 years at 1 MT/year
- Fuel fabrication: 10 years at 8 LTAs/year + 40 years at 4 LTAs/year
- Process Support & Development: 50 years at 10% of the bounding AFCF annual packaged waste volume

This rationale is based on the assumption that the AFCF will experience lower than the maximum production rates for much or all of its operating life, for a variety of reasons ranging from shutdowns for equipment maintenance, modification, or replacement to support changing technology designs, supporting the qualification of advanced fuel fabrication processes, and evaluating long-term stability or degradation of equipment and reagents in the high radiation environment. Periods of lower throughput would be expected to involve testing of processing alternatives during which there would be more startups and shutdowns and more time devoted to optimizing processing or material handling equipment.

These expected lifetime HLW and TRU waste volumes were used to estimate the storage requirements for HLW and TRU wastes in the event that no disposal pathway is available during the 50-year lifetime of AFCF. These calculations assume that each of the waste streams is packaged in accordance with the descriptions presented in Table 7.

Table 7. Expected Waste Packaging for HLW and TRU-Contaminated Wastes

Waste Form	Packaging/ Container	Container Size	Container Volume	Total Containers per Year NEPA Bounding Case
Cs/Sr	Engineered Containers	3.5" dia x 10' long cylinder	0.019 m^3	420
La/FP	HLW Containers	2' dia x 15' long cylinder	1.3 m^3	13
Hulls with Tc (HLW) or without Tc (TRU waste)	"Universal" Containers	2' dia x 10' long cylinder	0.9 m^3	2 with HLW 15 without HLW
Maintenance	SWB or equivalent (e.g., B-25 Box)	71" long x 54.5" wide x 36.5" high	1.88 m^3	11 TRU waste 10 mixed TRU waste
Job Control	SWB or Equivalent	71" long x 54.5" wide x 36.5" high	1.88 m^3	350

While these containers are assumed to enable calculations to support the GNEP PEIS and the EM EIS, future conceptual design will likely result in changes to these assumed containers. These expected lifetime waste volumes bound the waste volumes that would result from the proposed operations basis throughput (a nominal 20-25 MT/yr LWR SNF for aqueous separations, 1 MT/yr ARR SNF for electrochemical separations, and production of 4 LTAs/yr for fuel fabrication operations) for the AFCF, but they are lower than the estimates that would have resulted from simply multiplying the maximum annual waste volumes by the 50 year lifetime for AFCF. Thus, these expected lifetime waste volumes are more realistic estimates.

The shielded process area required for storing Cs/Sr, La/FP and metal (hulls) wastes have not been fully defined and depend on a number of factors such as container spacing requirements for heat removal, container stacking requirements, access space needed for moving containers through the storage area, and shielded equipment maintenance space. Preliminary designs of storage areas for the different types of waste containers have been used to estimate the shielded process area required per container for each container type. The Cs/Sr canisters would be stored in floor-storage locations that are sized to accommodate two canisters per location. The HLW containers and "universal" containers would also be stored in floor storage locations, but only one container would be stored in each location. The Standard Waste Boxes (or equivalent-size engineered container) would be stacked up to 3 containers high in a high bay so that the containers could be periodically inspected (remotely).

The estimated floor space requirement for the Cs/Sr canister storage is 1.54 ft^2/storage location, not counting the floor space required for support activities and access to the floor storage locations. HLW canisters would require 26.4 ft^2/storage location. The SWB equivalent packages would require 48 ft^2/location with three containers per location.

For the expected lifetime generation of aqueous-separated Cs/Sr wastes from the centralized Greenfield AFCF, refer to entries in Table 1. The Cs/Sr waste packaged volumes are:

$$10\,yr \times 7.3\,m^3/yr \;+\; 40\,yr \times 2.4\,m^3/yr \;+\; 50\,yr \times 0.7\,m^3/yr \;\approx\; 206\,m^3$$

The Cs/Sr wastes are packaged into engineered containers that have a packaged volume of 0.019 m^3 per package. This provides a total expected lifetime of 10,900 packages. Using the assumptions of 1.54 ft^2 per location with 2 packages per location yields a shielded storage area of 8400 ft^2 for the storage of Cs/Sr packaged wastes over the 50-year lifetime of the AFCF. This area accounts for the storage only and does not include spaces required to maintain equipment or to support operations.

The assumption is made that the High Level waste containers and Universal containers will be stored in floor storage locations with one container per storage location. There are 720 HLW container storage locations for the HLW and TRU waste packaged in HLW canisters with an estimated 26.4 ft^2/location. This yields a shielding storage area of 19,000 ft^2 for the HLW canisters. This area accounts for the storage only and does not include spaces required to maintain equipment or to support operations.

Job control wastes are described in reference 1 as being packaged in containers that are similar in size and shape to the Standard Waste Box (1.8 m^3 internal volume) currently used to package defense transuranic wastes for shipment to WIPP in TRUPACT II containers. For the purposes of this analysis, we assume that the containers can be stacked 3 high and that each stack requires 16 ft^2 of floor area. Waste generation estimates for these wastes results in an estimated lifetime generation of 12,770 containers, resulting in a total floor area for storage of 204,320 ft^2. This estimate does not include support spaces.

The expected lifetime HLW and TRU waste volumes and shielded storage area footprints are summarized in Table 8. The total shielded area for meeting the HLW and TRU waste storage requirements for the 50-year expected lifetime of the AFCF is estimated to be 231,900 ft^2 not including support spaces. Most of this area is for storing job control wastes that, in the AFCF NEPA Data Study, were expected to be processed by steam reforming or other volume reduction processes, and thus, the original AFCF waste storage facility does not include this shielded storage space.

These calculated storage space estimates underscore the result that the estimated job control wastes are orders of magnitude larger than other process wastes. The estimated storage space required for the job control wastes is almost 90% of the total waste storage space. Efforts to reduce the mass and volume of the job control waste through means not accounted for in the historical waste generation estimates might conceivably reduce the job control wastes by factors from 10 to 100, thereby also reducing the total space required for waste storage by almost a factor of 10.

Table 8. Expected Lifetime HLW and TRU Waste volumes and shielded storage area requirements for AFCF.

	Packages	**Storage Locations Required**	**Shielded Storage Area per Storage Location (ft^2)**	**Shielded Storage Area (excluding Support Space) (ft^2)**
Cs/Sr in Engineered Packages	10,900	5,450	1.54	8,400
HLW in HLW Canisters	360	360	26.4	9,500
TRU Waste in HLW Canisters	360	360	26.4	9,500
TRU Waste in SWBs (or equivalent)	12,770	4,260	16	204,500
Total				**231,900**

7.0 Summary of Results

The results of the waste volume and container volume calculations are summarized in Tables 9 and 10. Table 9 updates and replaces Table 4 from the AFCF NEPA Data Study[1].

Table 9. Estimates of SNF Processing Materials and Wastes

Feed/Product/Waste	NEPA Bounding Annual Product/Waste Form Mass Rate	NEPA Bounding Annual Volume (+10% for allowance for Process Support and Development Facility)	Total Annual Bulk Container Rate	Stream Description
Aqueous Separations (75 MTIHM LWR SNF/yr)				
LWR Fuel	75 MTIHM	—	150 LWR assemblies	Feed
UO_3 powder	79 MT	—	345 ea 35-gal drums	Product
Pu/Np oxide powder	1.5 MT	—	300 cans	Product
Am oxide powder	169 kg	—	365 cans (1/day)	Product
Cm oxide powder	49.5 kg	—	365 cans (1/day)	Product
Cs/Sr hydroceramic waste form	14 MT	8 m^3/yr	420 cans (3-1/2" ID x 10 ft long engineered canister)	HLW
FP/Lanthanide vitrified waste form	32 MT	14.2 m^3/yr	11 HLW-style canisters	HLW
C-14 waste	8.9 MT	4.5 m^3/yr	30 ea 55-gal drum	HLW
Iodine waste	1.9 MT	0.9 m^3/yr	5 ea 55-gal drums	HLW
Tc metal	156 kg	1.1 m^3/yr	2 HLW-style canisters	HLW
UDS	875 kg			
Hulls	6.2 MT			
	16.3 MT	6 m^3/yr	8 HLW-style canisters	TRU-Contaminated Waste
Other non-fuel-bearing Metal wastes	10.5 MT			
Job Control Wastes	—	330 m^3/yr	175 SWBs or equivalent	TRU-Contaminated Waste
Maintenance Wastes (Spent Equipment)	—	9 m^3/yr	5 SWBs or equivalent	TRU-Contaminated Waste
Maintenance Wastes (Spent Equipment)	—	7.9 m^3/yr	5 SWBs or equivalent	Mixed TRU-Contaminated Waste
Tritiated Water	15.5 kg	0.006 m^3/yr	1 ea 35-gal drum	Decay/LLW
Xe/Kr	1220 kg	—	3500 2-liter cylinders	Decay storage
Electrochemical Separation (ARR fuel, 2 MTIHM/yr)				
ARR Fuel	2 MTIHM	—	100 ARR assemblies	Feed
U metal	0.31 MT	—	2 ea 35 gal drums	Product
Pu/Np/Am/Cm/U Metal	1.2 MT	—	342 cans	Product
Glass-bonded ceramic FP (La/Cs/Sr/FP) waste form	4.8 MT	3.1 m^3/yr	2.5 HLW-style canisters	HLW
Metal waste (Hulls/Tc)	7.1 MT	1.6 m^3/yr	2 HLW-style canisters	HLW
Other non-fuel-bearing metal wastes	6 MT	1.3 m^3/yr	2 HLW-style canisters	TRU-Contaminated Waste
Job Control Wastes	—	220 m^3/yr	120 SWBs or equivalent	TRU-Contaminated Waste
Maintenance Wastes (Spent Equipment)	—	6.3 m^3/yr	3.3 SWBs or equivalent	TRU-Contaminated Waste
Maintenance Wastes (Spent Equipment)	—	5.6 m^3/yr	3 SWBs or equivalent	Mixed TRU-Contaminated Waste
Volatile FP wastes	Included in C-14, Iodine, Tritiated Water and Xe/Kr wastes for Aqueous Separations, above			
Fuel Fabrication (Ceramic ARR fuel, 2 MTHM/yr)				
Pu/Np/Am/Cm oxide powder feedstock	1.14 MT	—	225 cans	Feed

Table 9. Estimates of SNF Processing Materials and Wastes

Feed/Product/Waste	NEPA Bounding Annual Product/Waste Form Mass Rate	NEPA Bounding Annual Volume (+10% for allowance for Process Support and Development Facility)	Total Annual Bulk Container Rate	Stream Description
UO_3 powder feedstock	1.20 MT	—	6 ea 35 gal drums	Feed
ABR assemblies	2 MTHM	—	50 ARR LTAs	Product
Job Control Wastes	—	110 m^3/yr	55 SWBs or equivalent	TRU-Contaminated Waste
Maintenance Wastes (Spent Equipment)	—	5 m^3/yr	2.7 SWBs or equivalent	TRU-Contaminated Waste
Maintenance Wastes (Spent Equipment)	—	4.4 m^3/yr	2.3 SWBs or equivalent	Mixed TRU-Contaminated Waste
Low Level Radioactive Waste				
Low Level Waste (all sources)		2640 m^3/yr	1585 SWBs or equivalent	LLW
Mixed Low Level Waste (all sources)		3.4 m^3/yr	2 SWBs or equivalent	Mixed LLW

Table 10. Annual Radioactive Waste Volume Estimates for the three AFCF Operating Throughputs and Expected Lifetime Radioactive Waste Volume Estimates for the Centralized and Distributed AFCF Alternatives.

Waste Type	Maximum Operating Throughput Annual Quantity (m^3)	Design Operating Throughput Annual Quantity (m^3)	Nominal Operating Throughput Annual Quantity (m^3)	Centralized Greenfield or Brownfield Alternative Expected Lifetime Volume (m^3)	Distributed Alternatives Expected Lifetime Volume (m^3)
HLW	25.5	10.7	7.6	686	760
Cs/Sr Waste	8.0	3.1	1.9	206	226
TRU-Contaminated waste	692	444	371	22,471	24,718
Mixed TRU	17.9	7.9	6.0	416	458
LLW	2,640	1,720	1,440		
Mixed LLW	3.4	1.7	1.3		

Abbreviations and Acronyms

AFCF – Advanced Fuel Cycle Facility
AFCI – Advanced Fuel Cycle Initiative (program)
ARR – Advanced Recycle Reactor
CFR – Code of Federal Regulations
CFTC – Consolidated Fuel Treatment Center
EAS – Engineering Alternatives Study
F&OR – Functional and Operational Requirements
FP – fission products
FR – fast (neutron) reactor
GNEP – Global Nuclear Energy Partnership
GTCC – Greater-Than-Class-C low level radioactive waste
GWd/MT – gigawatt days per metric ton
HLW – High Level (Radioactive) Waste
IWMS – Integrated Waste Management Strategy
La/FP – lanthanide and fission products
LLW – Low Level (Radioactive) Waste
LTA – lead test assembly
LWR – Light Water Reactor
NEPA – National Environmental Policy Act
NFBC – non-fuel-bearing components
PEIS – Programmatic Environmental Impact Statement
SNF – spent nuclear fuel
SWB – standard waste box
TRU – transuranium elements
WIPP – Waste Isolation Pilot Plant

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